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RESEARCH ARTICLE

Soil nutrient evaluation from swine effluent application to five forage-system practices

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Abstract Many contract swine producers are located in the southeastern U.S. In this region almost all of the swine effluent from swine production is applied to warm-season perennial species such as bermudagrass [*Cynodon dactylon* (L.) Pers.] which is widely grown for summer grazing and hay production. A 3-yr study was conducted to investigate the impact of forage double-cropping on nutrient accumulation and leaching in Mantachie fine loam soil fertilized with swine (*Sus scrofa domesticus*) lagoon effluent as the source of plant nutrients. Plots of previously established Tifton 44 bermudagrass were overseeded in the fall with one of four winter annuals: berseem clover (*Trifolium alexandrinum* L.); crimson clover (*T. incarnatum* L.); ryegrass (*Lolium multiflorum* L.); or wheat (*Triticum aestivum* L.). Four plots of bermudagrass were not overseeded and considered as control. Plots were harvested in spring for cool-season annual hay and in summer for bermudagrass hay. Swine effluent was applied during spring and summer on a need base. Suction lysimeters were installed in selected plots at two depths to monitor nutrient leaching. Surface soil samples were taken to determine baseline nutrient contents, followed by three other sampling dates during the study. Bermudagrass dry matter production(3-yr average $= 9.8$ Mg ha^{-1}) was not adversely affected by the overseeding treatments. Greatest dry matter production was achieved with bermudagrass overseeded with ryegrass (3-yr average $= 11.3$ Mg ha^{-1}). Soil pH decreased by almost one unit by the end of the study. While total P (TP) did not change much, Mehlich-3 P (M3-P), K, Cu, and Zn increased significantly, Mg and Mn concentrations decreased by 2002 compared to the baseline levels. Soil P, Mg, K, Fe, Mn, and Zn accumulation were greater under bermudagrass/wheat combination. In general, the influence of double cropping on soil nutrient accumulation was not conclusive, however, this practice provides the year-round green forage for grazing and haying. Nutrient concentrations in soil and lysimeter leachate were directly related to the quantity of effluent applied. Results also demonstrated that effluent application must be coordinated with the nutrient requirements of the growing forages in order to minimize accumulation and leaching.

Keywords Forage · Swine effluent · Nutrient · Nitrogen · Phosphorus

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Introduction

Most effluent from swine production in the southeastern U.S. is applied to warm-season perennial forages, such as bermudagrass, which is widely grown for summer grazing and hay (Brink et al. 2003; Burns et al. 1985; King et al. 1985; Choudhary et al. 1996). Many contract swine producers are also located in this region (Welsh and Hubbell 1999). Research has shown that bermudagrass responds well to fertilization with swine effluent (Brink et al. 2003; McLaughlin et al. 2004). Since bermudagrass growth is restricted to the warm summer months, double-cropping warm-season bermudagrass with cool-season annual forages has been used successfully in grazing systems and could be applied to hay production fields, thus extending the forage production season. Cool-season annual forages seeded into dormant bermudagrass in the fall can provide more winter ground cover and earlier spring growth than bermudagrass alone (McLaughlin et al. 2001; Rowe and Fairbrother 2003).

Long-term animal manure application to pasture land can increase the potential for soil nutrient accumulation and leaching, which may impact surface and ground water quality (Daniel et al. 1998; Sistani et al. 2004). Previous research has found plant availability of P, K, and Cu to increase following swine lagoon effluent application to soil (King et al. 1990; Sharpley and Smith 1995). Nutrient uptake requirements, particularly P, by forage crops are often less than the quantity of applied manure nutrients because manure application rates are often based on the N requirement of the crop. Since the N:P ratio of plant uptake for most crops is approximately 8:1 and the same ratio for swine effluent is about 4–6:1, manure fertilization based on N rates can lead to accumulation of P in the surface soil (0–15 cm) (Edwards and Daniel 1992; Edwards 1996; Sharpley et al. 1993; Sims 1995).

Proper application of swine effluent has become a critical issue in manure nutrient management systems. To develop an accurate and reliable animal manure management practice, the fate of major manure nutrient constituents in the soil must be investigated. Forages can reduce the susceptibility of nutrient accumulation or loss, because of their influence in reducing soil erosion and runoff and their relatively high nutrient uptake capability.

The objective of this study was to investigate the effect of overseeding four cool-season annual forages into Tifton 44 bermudagrass fertilized with swine lagoon effluent on soil nutrient accumulation and leaching.

Materials and methods

Experimental description

The study was conducted in Choctaw County, Mississippi, USA (N33°16.9′, W89°14.1′). Experimental plots were located in a swine effluent spray field, on a Mantachie soil (fine-loamy, siliceous, acid, thermic Aeric Fluvaquents) with 0–2% slope. The spray field received anaerobic lagoon effluent and produced summer hay from a well-established stand of Tifton 44 bermudagrass. Bermudagrass was established from sprigs in 1996 and the field had been treated with effluent from June through October each year prior to the start of the study in 1999. Timing and amounts of effluent applications during the study were determined and recorded on the forages need base. Effluent amounts and total N, P, and K and other micronutrients applied in effluent are shown in Table 1.

Baseline soil nutrient levels (0–10 cm) of the site were measured at the start of the study in October 1999 (Tables 2, 3) by collecting three soil probes from each plot, combined, mixed, air-dried, ground to pass 2 mm sieve for chemical analysis. Three more annual soil sampling dates were conducted during the study until October 2002. Rainfall records of the spray field were obtained from the National Weather Service close to the study site (Fig. 1). Although rainfall during the first year of the study was below normal, timely effluent applications in September 1999 (88 m^3) and June–September 2000 (615 m^3) served to minimize the effects of the drought. Effluent applications to the plots were collected and measured using four meteorological rain gauges placed in each block of the experiment. Volumes of four replicate samples were recorded immediately after each effluent application and the samples were combined and frozen for subsequent nutrient analysis (Brink et al. 2001).

Table 1 Annual nutrient application of swine lagoon effluent

Year	Effluent applied m^3	N	P	K	Cu	Fe	Mn	Zn
		kg ha $^{-1}$						
2000	703	598	78	359	0.04	1.27	0.15	0.16
2001	508	361	69	259	0.03	0.91	0.11	0.11
2002	180	138	21	92	0.01	0.32	0.04	0.04
3-yr total	1391	1097	168	710	0.08	2.50	0.29	0.31

Table 2 Soil pH and nutrient concentrations at 0–10 cm for baseline and subsequent sampling dates

Date	pH	TC[a] g/kg	TN	NO_3–N	NH_4–N mg/kg	TP	M3-P
Baseline (Oct-99)	7.35b	10.42a	0.96a	184a	4.3bc	348a	44c
Oct-00	7.79a	10.16a	0.97a	136b	5.1b	353a	115a
Oct-01	6.40c	9.81ab	0.91ab	28c	2.8d	321b	67b
Oct-02	6.44c	9.23b	0.84b	28c	3.9c	345a	66b
LSD	0.15	0.87	0.08	7.00	0.80	23.0	13.0

[a] Total carbon (TC), total N (TN), total P (TP) and Mehlich 3-P (M3-P)

LSD (least significant difference) at $P < 0.05$ compares each column

Table 3 Soil nutrient concentrations at 0–10 cm for baseline and subsequent sampling dates

Date	Ca	Mg	K	Cu mg/kg	Fe	Mn	Zn
Baseline (Oct-99)	616a	685a	104c	0.70c	343b	204a	0.50d
Oct-00	610a	80b	740a	1.98a	375a	190b	2.18a
Oct-01	590a	80b	510b	1.16b	269c	163c	1.52c
Oct-02	610a	100b	480b	1.41b	227d	153d	1.57c
LSD	50	47	30	0.27	13	8	0.16

LSD (least significant difference) at $P < 0.05$ compares each column

Experimental plots were 2 by 5 m and were separated and surrounded by 1-m alleys and borders. Overseeding treatments consisting of four cool-season annual forages, berseem (*Trifolium alexandrinum* L.) and crimson (*T. incarnatum* L.) clovers, ryegrass (*Lolium multiflorum* L.), and wheat (*Triticum aestivum* L.), plus a standard practice (non-overseeded) Tifton 44 bermudagrass [*Cynodon dactylon* (L.) Pers.] as control were arranged in a randomized complete block design replicated four times. For a detailed explanation of materials and methods refer to McLaughlin et al. (2005).

To monitor nutrient leaching, 4 suction lysimeters each were installed at 30 and 60 cm soil depth within pure bermudagrass, bermudagrass–berseem clover, and bermudagrass–ryegrass plots, leading to 12 lysimeters in total. Water samples were collected periodically (before, during and after summer growing seasons) from each lysimeter during 2001 and 2002.

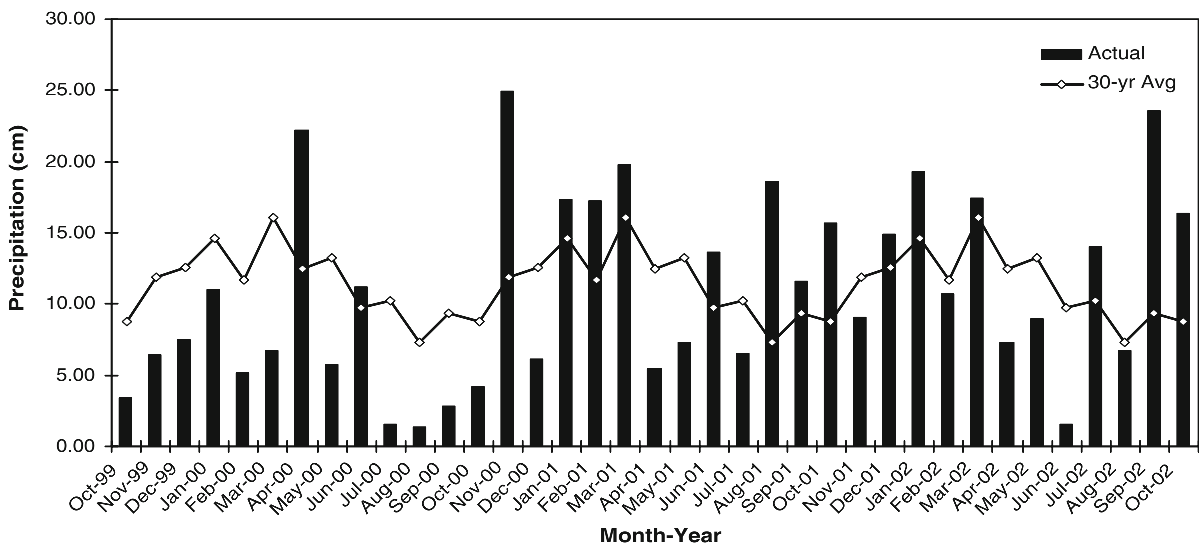

Fig 1 Actual and 30-yr mean monthly precipitation during the course of the experiment. Data were recorded by the National Weather Service in the vicinity of the experimental plots

Chemical analysis

Soil pH was measured in a 1:1 soil:water ratio using 10 g soil. Soil and plant total N (TN) and total carbon (TC) were measured by dry combustion using a CE Elantech (Lakewood, NJ) CN analyzer. Soil samples (2 g) were extracted with 0.01 M KCl (1:10 soil:KCl) (Mulvaney 1996) and analyzed for nitrate (NO_3^-–N) and ammonium (NH_4^+–N) using a Dionex-500 Ion Chromatograph (Sunnyvale, CA). Soil samples (2 g) were extracted with Mehlich-3 soil extractant (Mehlich 1984), 1:10 soil:extractant, shaking for 30 min, and filtered through Whatman Fisher brand filter paper (2 V) for the determination of P and metals using a Thermo Jarrell-Ash Inductively Coupled Plasma Spectrophotometer (ICP), (Franklin, MA). Soil samples were also extracted with deionized water (1:10 soil:water ratio) for water extractable P (WP). Soil total P (TP) was determined by digesting 0.5 g of air-dried soil using sulfuric acid, hydrogen peroxide, and hydrofluoric acid (Kuo 1996) followed by the determination of P using the ICP. The effluent TN concentration was determined by the Kjeldahl procedure with a salicylic acid modification (Bremner 1996). Total effluent P and other selected secondary and micronutrients were determined by digesting a 20-ml sample containing 1 ml of concentrated H_2SO_4 and 5 ml of concentrated HNO_3 to a total volume of 1 ml, diluting with 40 ml of distilled water, and filtering through Whatman 2 V paper followed by the determination of concentration using the ICP. The effluent nutrient concentration was used to calculate the total quantity of nutrients applied annually.

Data were analyzed using PROC GLM procedure of SAS (Statistical Analysis System 1998). Mean comparisons were done using Fisher's protected LSD ($P < 0.05$).

Results and discussions

Dry matter yield

The cumulative annual dry matter (DM) yield reported here is the total of spring harvests for overseeded cool-season annuals plus corresponding summer harvests of Tifton 44 bermudagrass from the same plots (total of five harvests) (Fig. 2). The DM for non-overseeded bermudagrass treatment (standard practice), which was considered as control, consisted of only the summer harvests of bermudagrass. For a more detailed analysis of DM related to each harvest (cutting) and related nutrient uptake refer to McLaughlin et al. (2005). The mean cumulative DM yields of ryegrass and wheat treatments (15.4 Mg DM ha^{-1}) were greater in 2000 than other treatments, which is attributed to the lush growth of little barley in the first harvest. However, this problem was eliminated by herbicide application for other treatments. In 2001, mean cumulative DM yield did not differ among overseeding treatments but berseem clover had a slightly greater average (11.8 Mg DM ha^{-1}). In 2002, berseem clover produced significantly higher DM yield (9.3 Mg DM ha^{-1}) than the other treatments, which were 7.1, 7.7, 6.7, and 6.9 Mg DM ha^{-1} for ryegrass, crimson clover, wheat, and control treatments, respectively (Fig. 2). The greater DM yield of berseem clover in 2002 could be attributed to N fixation, which provided more N under low effluent application. The Tifton 44 bermudagrass DM (3-yr mean) of 9.8 Mg ha^{-1} was within the range or slightly lower than previously reported values (Adeli and Varco 2001; Adeli et al. 2003; Brink et al. 2003). No adverse effects of overseeding cool-season annual species were detected on the DM yield of bermudagrass. Ryegrass and berseem clover were the best candidates for this management practice, and consistently produced numerically greater DM yields in all three years.

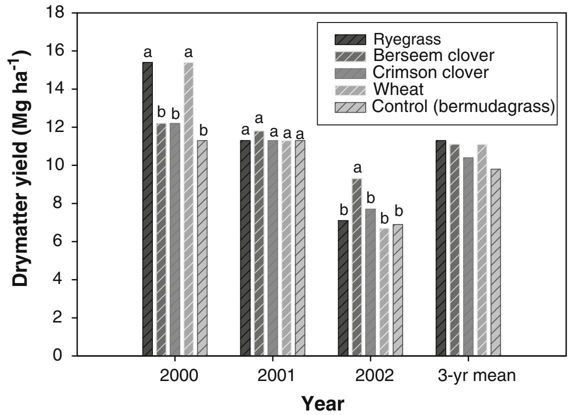

Fig 2 Annual dry matter (DM) yield of four cool-season annual forages overseeding Tifton 44 bermudagrass

Soil nutrient dynamic and leaching

Significant differences were observed among sampling dates for most of the elements. However, no significant differences were determined in leachate nutrient concentrations among different winter annuals. Therefore, results for leachate nutrient concentrations were averaged and reported on the sampling dates. Soil pH increased in the first year of the study (2000), then decreased significantly by almost a unit by the end of the study (Table 2). Soil TC decreased consistently during the study. In October 2002, soil TC was decreased by more than 11% compared to the baseline soil TC measured in October 1999 (10.42 g kg^{-1}). Soil TN followed the same trend as TC, did not change much in 2000 and 2001 then decreased significantly by October 2002. The decrease in soil TC and TN can be attributed to the low effluent application in 2002 (180 m^3) compared to 703 and 508 m^3 in 2000 and 2001, respectively (Table 1). In 2000, a very dry year (Fig. 1), soil inorganic N was greater than 2001 and 2002. The leachate NO_3^-–N concentration was extremely high during 2001 compared to 2002. The effluent application was much greater in 2001 than 2002 meaning a direct relation between leachate NO_3^-–N concentration and the quantity of yearly effluent application (Tables 1, 4). Almost all the inorganic N in the leachate was in the form of NO_3^-–N relative to NH_4^+–N concentration.

The decrease in NO_3^-–N was due to leaching as indicated by high NO_3^-–N concentration of the leachate samples collected from suction lysimeters in 2001 and 2002 (Table 4).

The soil TP concentration in October 2002 (345 mg kg^{-1}) did not differ from initial soil TP in 1999, however, in 2001 the soil TP decreased to 321 mg kg^{-1} compared to initial soil TP (Table 2). In contrast to soil TP, the soil M3-P increased significantly during the study compared to initial soil M3-P (44 mg kg^{-1}).

There was a drastic decrease in soil Mg and Mn, while K, Cu, and Zn concentrations increased during the study compared to the initial soil concentrations of these nutrients (Table 3). However, soil Ca concentration did not change during the same time. The pH of the leachate collected from the suction lysimeters during 2001 and 2002 ranged from 5.5 to 6.1 (Table 4). Greater concentrations of Ca, Mg, K, and Mn were measured in the leachate water samples from August 2001 to October 2002 compared to the measurements from January 2001 to June 2001. No significant trend was observed with regard to the concentrations of Cu, Fe, and Zn (Table 4).

Soil pH under all forage systems decreased (Table 5) compared to the baseline soil pH (Table 2). The pH reduction was as high as 1.2 unit for bermudagrass/ryegrass and as low as 0.6 unit for bermudagrass/wheat (Table 5). The differences among different forage systems with regard to soil TC, TN, and inorganic N accumulation were not substantial. However, soil TP and M3-P concentrations under bermudagrass/wheat system were significantly greater than other combinations, indicating the inefficiency of this system in P utilization compared to other forage combinations (Table 5). Read et al. (2007) reported that harvesting ryegrass in

Table 4 pH and nutrient concentrations of leachate water from suction lysimeters collected at differen dates

Date	pH	NO_3–N	NH_4–N	P	Ca	Mg	K	Cu	Fe	Mn	Zn
						mg/L					
Jan-01	6.1	179.00	0.14	0.00	0.03	0.01	0.01	0.00	0.01	1.26	0.08
Feb-01	5.6	233.00	0.14	0.02	0.04	0.01	0.01	0.00	0.00	1.36	0.06
Mar-01	5.7	223.00	0.06	0.01	0.03	0.01	0.01	0.01	0.01	1.88	0.08
May-01	5.5	181.00	0.05	0.00	0.03	0.01	0.01	0.00	0.01	1.59	0.08
Jun-01	6.0	104.00	0.59	0.00	0.03	0.01	0.01	0.00	0.19	1.81	0.07
Aug-01	5.9	8.90	0.01	0.02	17.20	6.20	4.32	0.00	0.01	0.45	0.04
Jan-02	6.0	16.90	0.01	0.04	30.10	12.00	6.86	0.00	0.03	2.14	0.04
Jun-02	5.7	1.90	0.01	0.01	23.00	9.10	7.20	0.00	1.01	2.23	0.07
Oct-02	5.8	1.10	0.01	0.02	22.60	9.20	10.13	0.00	0.07	1.56	0.03
LSD	0.3	0.34	0.01	0.07	6.40	2.60	4.50	0.01	0.67	0.68	0.03

LSD (least significance difference) at $P < 0.05$ compares each column

Data points are averages of two depth, three treatments, and four replicates

Table 5 Final soil pH and nutrient concentrations (0–10 cm) under different forage systems in 2002

Treatment	pH	TC[a]	TN	NO_3–N	NH_4–N	TP	M3-P
		g/kg			mg/kg		
Bermudagrass/Ryegrass	6.2c	9.2	0.86	31.2a	4.74a	331b	59.7b
Bermudagrass/Wheat	6.8a	9.4	0.83	30.3ab	1.93c	384a	104.6a
Bermudagrass/Berseem clover	6.2c	9.5	0.87	27.9ab	4.85a	329b	51.5b
Bermudagrass/Crimson clover	6.5b	8.9	0.79	25.2b	3.44b	335b	51.2b
Bermudagrass	6.4b	9.1	0.88	26.6ab	4.86a	341ab	58.1b
LSD	0.2	1.3	0.16	5.70	0.96	46	15.0

[a] Total carbon (TC), total N (TN), total P (TP), and Mehlich-3 P (M3-P)

Least significant difference (LSD) at $P < 0.05$ level compares each column

addition to bermudagrass increased P uptake by 10 to 55%. They also mentioned potential to decrease surplus soil P by ryegrass–bermudagrass hay harvest under low rainfall condition. Soil Mg and Mn concentrations decreased drastically, while soil K, Cu, and Zn concentrations increased under all forage systems compared to their corresponding baseline soil concentrations (Table 6). The quantity of effluent application, nutrient uptake, and leaching may have contributed to the soil nutrient concentrations.

The management practice of using cool-season annual species overseeded in bermudagrass, a warm-season perennial has many advantages including removing nutrients from soil during bermudagrass dormancy (Shipley et al. 1992) in winter months, and also providing nearly year-round forage production for grazing or haying. It may also be used as justification for the extended application of effluent beyond the time limit mandated by Natural Resource Conservation Service (NRCS) Code 359, Waste Treatment Lagoon, which prohibits effluent application in Mississippi from October 1 to March 31 (Mississippi Natural Resources Conservation Service 2000). Generally, annual and perennial forage crops serve as an important component of nutrient management plans for farms where animal manure is routinely applied. However, producers will often choose a particular forage species or cultivar for other reasons, including forage quality, seasonal distribution of growth, and cost of establishment. Therefore, the statistically significant but relatively small differences in nutrient build up in soil may become significant in a long-term effluent application.

Implication and conclusion

Growth of common bermudagrass was not adversely affected by overseeding with any of the cool-season annual forages tested. Overseeding bermudagrass with berseem clover or annual ryegrass was found to be an advantageous practice compared to growing bermudagrass alone. This practice provides the year-round green forage for grazing and haying. However, the influence of double cropping on soil nutrient accumulation was not conclusive. Most nutrients from swine lagoon effluent fluctuated in soil during

Table 6 Final soil nutrient concentrations (0–10 cm) under different forage systems in 2002

Treatment	Ca	Mg	K	Cu	Fe	Mn	Zn
				mg/kg			
Bermudagrass/Ryegrass	531b	85c	449c	1.48ab	226b	135c	1.51b
Bermudagrass/Wheat	651a	110a	580a	1.21c	272a	172a	2.01a
Bermudagrass/Berseem clover	640a	98ab	398d	1.44ab	204b	147bc	1.43b
Bermudagrass/Crimson clover	621ab	89bc	491b	1.36b	211b	167ab	1.35b
Bermudagrass	634ab	96bc	459bc	1.55a	216b	142c	1.52b
LSD	104	13	34	0.15	25	21.0	0.3

Least significant difference (LSD) at $P < 0.05$ level compares each column the 3-yr study in an arbitrary manner. The concentration of nutrients in soil and leachate, however, was positively related to the quantity of effluent application. The quantity of the effluent application must be properly coordinated with the nutrient requirements of the growing forages in order to minimize the accumulation or leaching of any nutrient in the soil.

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